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COMPARISON OF PITCH RATE HISTORY EFFECTS ON DYNAMIC STALL

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1. INTRODUCTION

Dynamic stall of an airfoil is a classic case of forced unsteady separated flow. Flow separation is brought about by large incidences introduced by the large amplitude unsteady pitching motion of an airfoil. One of the parameters that affects the dynamic stall process is the history of the unsteady motion, (McCroskey [1]). In addition, the problem is complicated by the effects of compressibility that rapidly appear over the airfoil even at low Mach numbers at moderately high angles of attack. Consequently, it is of interest to know the effects of pitch rate history on the dynamic stall process. This abstract compares the results of a flow visualization study of the problem with two different pitch rate histories, namely, oscillating airfoil motion and a linear change in the angle of attack due to a transient pitching motion.

2. DESCRIPTION OF THE RESEARCH

Stroboscopic schlieren studies were conducted while a 3 in. chord, NACA 0012 airfoil was executing unsteady motion. Two separate motion histories were considered. The first was a sinusoidal variation of the angle of attack and the second was a rapid ramp motion of the airfoil. Two independent drives were designed to produce the necessary pitch rate histories and are described in Carr and Chandrasekhara[2] and Chandrasekhara and Carr[3] respectively. A large body of data enveloping a Mach number M = 0.2 - 0.45 was collected. Since the pitch rate continuously changes for an oscillating airfoil, the angles of attack at

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which the pitch rates match were obtained by comparing them with those available for the ramp type motionexperiment. The angle of attack was varied from 0 - 60^0 in the ramp motion. The corresponding variation for the oscillatory motion was

$$\alpha = \alpha_0 + \alpha_m sin(\omega t) = 10^0 + 10^0 sin(\omega t)$$

Data was also obtained at other values of the amplitude of oscillation (2^0 and 5^0). However, to achieve a proper comparison, only the case of 10 degree amplitude that results in a total angle of attack range of 0 - 20^0 will be used.

3. RESULTS AND DISCUSSION

Fig. 1 shows the schlieren pictures at M = 0.2 at an instantaneous angle of attack of approximately 17^0 for the two pitch rate histories at a non-dimensional pitch rate defined as $\alpha^+ = \frac{\dot{\alpha} c}{U_\infty} = 0.025$. As can be seen from the figure, the flow over the airfoil in ramp motion has already reached deep stall conditions, whereas that over the oscillating airfoil shows a clearly defined dynamic stall vortex at 60% chord location, indicating that the airfoil is still producing dynamic lift. At a higher α^+ value of 0.03, the two flows are nearly identical even at an angle of attack of $\approx 15^0$.

Similar results were obtained at M = 0.25, 0.3 and 0.35. In all cases, at low pitch rates, deep stall occured over the airfoil in ramp type motion at the angles of attack for which the flow over the oscillating airfoil was dominated by a strong, tightly wound dynamic stall vortex which was still located over the upper surface. This result was true, despite the fact that at lower angles of attack, the two flows appeared nearly identical. In addition, in instances where the dynamic stall vortex could still be identified for the transient pitching case, it was significantly diffused, indicating that it was in a disorganised state as opposed to the oscillating case, where it was well organised. This trend persisted in the Mach number range that extended into the compressible regime, namely beyond M = 0.3. A table of the results for the different conditions is included to summarise the results discussed.

It is somewhat surprising to note the trends obtained in this comparison. An explanation of this effect could be offered for this as follows: A sinusoidal motion produces pitch rates that increase from 0 to 0.035 during the pitch-up phase for k = 0.1 and an amplitude of 10 degrees. Its maximum occurs at the mean angle of attack. Beyond this, the pitch rate decreases, but at the angle at which the comparions were made (17.07^0) in Fig. 1 , the pitch rate is still significant (0.025). For the ramp motion, the pitch rate reaches a constant value by $\alpha \approx 6^0$. Chandrasekhara and Carr[4] have shown that stall can be delayed to higher angles of attack by increasing the pitch rate. It appears from the pitch rate variation with angle of attack that an oscillating motion can produce higher amounts of vorticity which will cause the dynamic stall vortex to be more organised and coherent. This leads to the conclusion that motion with continuously changing acceleration can support larger flow gradients and thus is more desirable.

4. CONCLUSIONS

The study shows that pitch rate history is a very important parameter in the analysis of dynamic stall. Pitch rate history plays a dominant role by controlling the strength and behavior of the dynamic stall vortex. Vorticity created by repetitive motion appears to have the energy to sustain higher pressure gradients in the flow.

5. REFERENCES

1. McCroskey, W.J., "The Phenomenon of Dynamic Stall", NASA TM 81264, March 1981.

2. Carr, L.W. and Chandrasekhara, M.S., "Design and Development of a Compressible Dynamic Stall Facility", *AIAA Paper No. 89-0647*, Jan. 1989.

3. Chandrasekhara, M.S. and Carr, L.W., "Design and Development of a Facility for Compressible Dynamic Stall Studies of a Rapidly Pitching Airfoil", *Proc. 13^{th} ICIASF*, Goettinegen, W.Germany, September 1989.

4. Chandrasekhara, M.S. and Carr, L.W., "Flow Visualization Studies of the Mach Number Effects on the Dynamic Stall of an Oscillating Airfoil", *AIAA Paper No. 89-0023*, Jan. 1989.

Table 1. Comparison of Pitch Rate History Effects through Flow Visualization

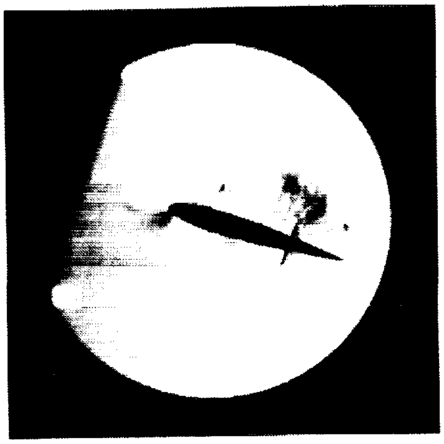
	M = 0.2, k = 0.1		
No.	Ramp Type Motion	Oscillatory Motion	α^+
1.	$\alpha = 17^0$ Nearly deep stall Transverse scales large	$\alpha = 17.07^0$ Tightly wound vortex at $\approx$60% chord	0.025
2.	$\alpha = 15^0$ Flow nearly identical in both cases	$\alpha = 15.23^0$	0.03
	M = 0.2, k = 0.075		
1.	$\alpha = 13^0$ Very nearly identical flow in both cases	$\alpha = 13.82^0$	0.025

M = 0.25, k = 0.1			
1.	$\alpha = 18^0$ Deep stall, trailing vortex, large transverse flow scales	$\alpha = 18.1^0$ Vortex at 75% chord and well organised	0.02
2.	$\alpha = 17^0$ Vortex present, but disorganised at 55%chord Indications of flow breakdown	$\alpha = 17.07^0$ Well organised vortex at 50% chord	0.025
3.	$\alpha = 15^0$ Flow very nearly similar in the two cases	$\alpha = 15.23^0$	0.03
M = 0.25, k = 0.075			
1.	$\alpha = 16.5^0$ Deep stall. Shear layer vortex at mid-chord, large transverse scales	$\alpha = 16.5^0$ Well organised at vortex $\approx 60\%$	0.02
2.	$\alpha = 13^0$ Beginnings of a vortex	$\alpha = 13.5^0$ Imprint of a vortex	0.025

M = 0.3, k = 0.1			
1.	$\alpha = 18^0$ Vortex well above the surface, near deep stall large transverse disturbance Disorganised flow	$\alpha = 18.1^0$ Vortex near 90% chord transverse disturbance getting larger	0.02
2.	$\alpha = 17^0$ Vortex at 65% chord flow getting disorganised, large vortex	$\alpha = 17.1^0$ Vortex at $\approx$55-60% chord Well organised flow	0.025
3.	$\alpha = 15^0$ Vortex at 15% chord Other features of flow nearly alike	$\alpha = 15.23^0$ vortex at 15% chord	0.03
M = 0.3, k = 0.075			
1.	$\alpha = 16.5^0$ Total flow breakdown	$\alpha = 16.5^0$ organised vortex at 55% chord	0.02
2.	$\alpha = 13^0$ Flow nearly identical in the two cases	$\alpha = 13^0$	0.025

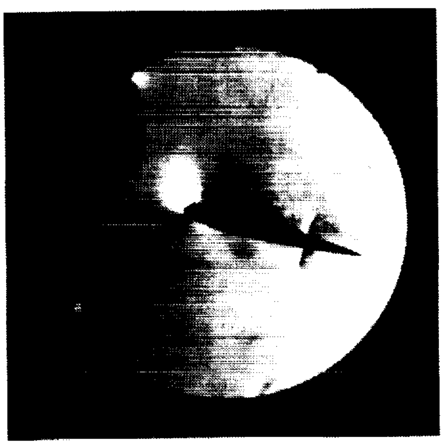
M = 0.35, k = 0.1			
1.	$\alpha = 17^0$ Large vortex, but not organised	$\alpha = 17.07.1^0$ Organised large vortex at the same location	0.025
2.	$\alpha = 15^0$ Vortex at 30% chord Otherwise nearly identical flow	$\alpha = 15^0$ votrex at 25% chord	0.03

Ramp motion | Oscillatory motion

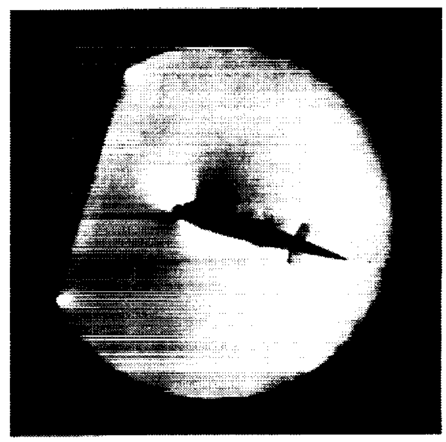


$\alpha^+ = 0.025$

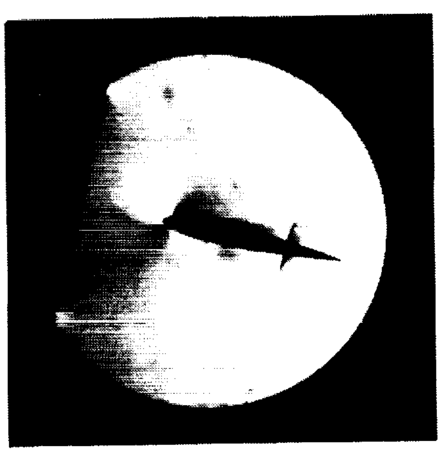
$\alpha = 17°$ | $k = 0.10$, $\alpha = 17.07°$



$\alpha^+ = 0.03$



$\alpha = 15°$ | $k = 0.10$, $\alpha = 15.23°$



$\alpha^+ = 0.025$

$\alpha = 13°$ | $k = 0.075$, $\alpha = 13.82°$

Figure 1. Comparison of Pitch Rate History Effects
(M = 0.20)

METHOD

Produce different unsteady airfoil motions

1. Oscillating airfoil

$$\alpha = 10^\circ + 10^\circ \sin \omega t, \ (0 \leq \alpha \leq 20^\circ)$$

2. Transient pitching airfoil

$$\alpha = c\, t, \ (0 \leq \alpha \leq 60^\circ), \ \dot{\alpha} = \text{constant}$$

Compare flow over airfoil at the same α at which the pitch rates match

Nondimensional pitch rate is defined as

$$\alpha^{+}_{ramp} = \frac{\dot{\alpha} c}{U_\infty} \quad , \quad \alpha^{+}_{osc} = 2k\alpha_m \cos \omega t$$

$$k = \frac{\pi f c}{U_\infty}$$

APPROACH

Conduct stroboscopic schlieren flow visualization for

$$0.2 \le M \le 0.45$$

$$0 \le k \le 0.1$$

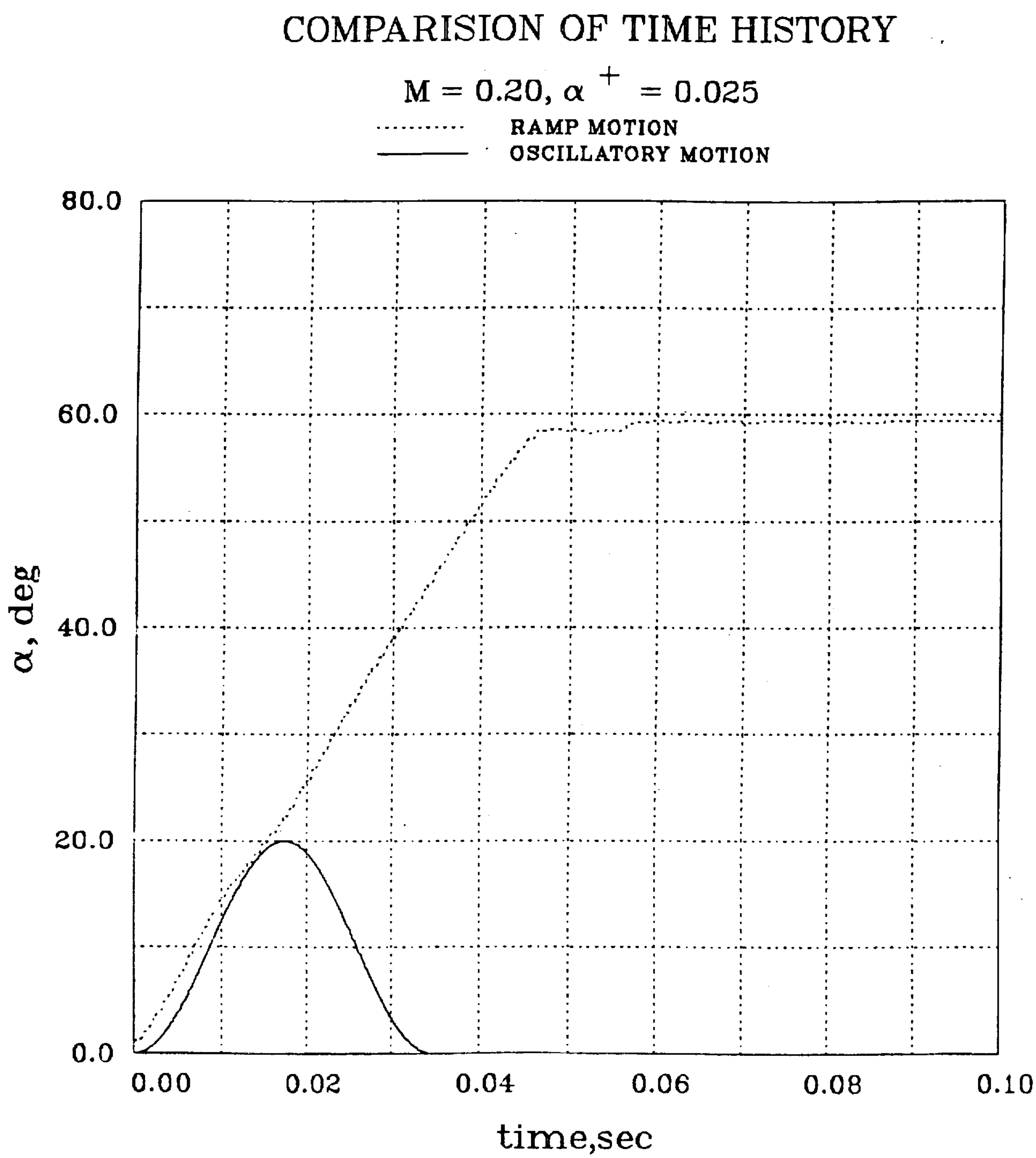
$$0 \le \alpha^+ \le 0.045$$

Compare schlieren pictures at the <u>same α</u> for different M, reduced frequency, and α^+

CONCLUDING REMARKS

1. Pitch rate history has significant effect on dynamic stall process and vortex behavior

2. Stall is alleviated when motion history produces changing acceleration



Run No. 00129B

SLOPES	0 – 10 Deg:	1510.68
	0 – 30 Deg:	1309.37
	0 – 57 Deg:	1285.50

VARIATION OF PITCH RATE WITH ANGLE OF ATTACK